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ABSTRACT

It is postulated that many types of renewable energy resources, like fossil fuels, are amenable to regional availability analysis. Among these are hydropower, geothermal, ocean temperature gradient, wind, and direct solar energy. A review of the spatial attributes of each of these types reveals areas of the United States that contain comparative advantages for the conversion of one or more of these alternative forms into electrical energy. Combining the results of five separate studies produces a generalized map of alternative energy supply regions within the United States. (Author/JN)

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TOWARD A REGIONAL GEOGRAPHY OF RENEWABLE ELECTRICAL ENERGY RESOURCES

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ABSTRACT

Abstract. It is postulated that many types of renewable energy resources, like fossil fuels, are amenable to regional availability analysis. Among these are hydropower, geothermal, ocean temperature gradient, wind, and direct solar. A review of the spatial attributes of each of these types reveals areas of the United States that contain comparative advantages for the conversion of one or more of these alternative forms into electrical energy. Combining the results of these five separate studies produces a generalized map of fourteen alternative energy supply regions within the United States.

Key Words: Energy supply, alternative energy, renewable energy, energy regions, solar energy.

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TOWARD A REGIONAL GEOGRAPHY OF RENEWABLE ELECTRICAL ENERGY RESOURCES

The problems and limitations of fossil fuels are well known. Domestic production of petroleum and natural gas has now been declining for over a decade. Coal, while plentiful, is relatively more polluting. Its increased use, widely advocated by energy experts, will result in either dirtier air and acidified lakes, or in sharply increased costs to prevent them. Most renewable and other alternative energy forms still have unfavorable economic characteristics compared with fossil fuels, but do have the promise of decreasing future price curves, at least in relative real dollar terms. Thus, the suggestion that in the future alternative forms of energy must be pursued as substitutes for fossil fuels has formed a main conclusion of many recent studies on the subject of energy (Domestic Policy Review, 1979; Schurr et al., 1979; Stobach and Yergin, 1981). This would not be difficult; in 1980 only about six percent of United States energy was from non-fossil fuel sources (Table 1).

In addition to quantitative studies, the spatial or regional aspects of energy merit examination as well. Previous studies have treated the regional aspects of the fossil fuels (Cook, 1976), but many alternative forms of energy can also be differentiated in terms of their regional abundance. This topic has been little explored to date. The purpose of this study is to examine spatially the better known of the electricity producing renewable energy resources of the United States, and to suggest whether any states or regions might have the

Table 1. United States Production and Consumption of Energy by Type

Energy Type	Quads, 1980 Production	Consumption
Coal	18.9	15.6
Oil[a]	20.5	34.2
Natural Gas	19.7	20.5
Hydroelectric	2.9	3.1
Nuclear	2.7[b]	2.7[b]
Other[c]	0.1[c]	0.1[c]
Totals:	64.9	76.2

[a]"Oil" includes crude oil and LNG under 'Production,' and all types of liquid hydrocarbons under 'Consumption'.

[b]These figures represent steam energy, not electrical energy. The electrical energy production from U.S. nuclear plants in 1980 equalled about 1 Quad.

[c]Includes geothermal, wind, solar, and bio-feedstocks.

Source: D.O.E., Monthly Energy Review, July 1981, pp. 4-7.

potential to approach electrical self-sufficiency on the basis of locally available alternative energy resources.

The Concept of Renewable Energy

"Renewable energy" is an imprecise term, and needs to be defined in the context of this study. The most common binary classification for energy resources is into the categories of renewable and non-renewable. However, a few types of energy, such as geothermal or nuclear fusion reactors, do not fit comfortably into either of these categories. A more sophisticated classification system would include a category of "semi-renewable," and would also more accurately describe fusion as "non-depletable" rather than "renewable." Such a classification system should also distinguish between primary and secondary energy resources, secondary ones referring to those such as electricity or methanol that are fabricated from a primary (naturally occurring) energy resource such as petroleum or coal (Table 2).

"Alternative energy resources," as the term will be used in this study, refers to any energy form other than the three common fossil fuels (oil, coal, and natural gas). As is evident from Table 2, not all alternative forms of primary energy fall into the category of "renewable." For example, the number of years that geothermal production can be sustained at any one site is unknown; the heat supply at the site may or may not be indefinitely renewable. As another example, some would question the ultimate renewable nature of hydroelectric plants on storage reservoirs as such reservoirs will eventually be lost to siltation. Nevertheless, for the sake of brevity, the alternative

Table 2. Categories of Energy Resources

Primary*		Secondary**
Renewable	**Non-Renewable**	
Solar Related: Direct solar Wind Biomass (energy farms) Ocean thermal Falling water (hydropower)*** Tidal	Fossil Fuels: Coal Oil Natural Gas Biotic: Peat Wood (without replanting)	Electricity Gasoline, Kerosine, etc. Hydrogen "Synfuels" (liquid or gaseous fuels derived from coal or other hydrocarbon sources other than petroleum)
Semi-Renewable**		
Geothermal Nuclear fission (uranium) Biogas (depending on source)		
Non-Depletable		
Nuclear fusion (deuterium)		

*A source which is found in an exploitable form in nature.
**A fuel or energy source derived from a primary form of energy.
***The storage capacity of reservoirs at hydroelectric facilities may have a finite life due to sedimentation.
****Geothermal presumed depletable at any one well; fission based on a finite U_{238} supply.

energy resources to be discussed in this paper, which include geothermal, will be referred to as "renewable."

Not all alternative energy resources lend themselves to a regional analysis. Resources which are easily transportable over thousands of kilometers, such as nuclear fuel and liquid or gaseous hydrocarbons (including synthetic fuels), provide no particular regional advantage to their areas of origin. Likewise, ubiquitous resources, such as biomass (here used to include biological waste products), also offer little significant regional advantage for electricity production. This study will consider five alternative energy resources (hydroelectric, ocean thermal, geothermal, wind, and direct solar) whose end product is electrical energy, and which clearly are differentiable regionally. These five all provide energy that is most economical if used in the immediate region of origin, and which, if found in abundance, will serve to move such a region towards electricity self-sufficiency.

Limitations of the Study

Efforts at discussing potential regional energy self-sufficiency encounter certain inherent limitations. First, the bulk of most regional energy consumption is made up of two dominant components, electricity and motor vehicle fuels. Of these, electricity is far more amenable to regional self-sufficiency studies than are vehicle fuels. Motor vehicle fuels, even if produced from a plentiful resource in a low population area, would probably be marketed through pipelines by a major oil company on a national basis. One possible exception to this,

gasohol, by definition couldn't offset more than ten percent of local gasoline sales, and pure alcohol as a widespread motor vehicle fuel seems improbable for the foreseeable future. Other forms of energy, such as heating oil and industrial fuel oils, are only partially amenable to locally supplied substitutions. Thus total energy independence for any region within the United States is fairly unlikely, barring major economic disruptions. For these reasons we will confine our attention to just the electricity component of regional energy supplies. Electricity is the most versatile form of energy, and is widely used in all consuming sectors except transportation.

Second, since we are dealing with future scenarios, precise quantification of energy supplies becomes difficult. As a result, we will be constrained to talk in a general way about high, moderate, or low amounts of possible future regional electrical self-sufficiency.

Third, concentrations of population also make discussions of regional energy self-sufficiency somewhat complex. All large urban agglomerations, such as southern California, must be supplied with most of their material needs, including energy, from a vast hinterland. The irony here is that probably few other areas of the country have as much total renewable energy available as does California, and if it had a tenth its present population, California could undoubtedly be energy self-sufficient. On a per capita basis, however, California can only be listed as having "moderate" potential for renewable energy independence. Since any discussion of potential "self-sufficiency" must obviously take population into account, we will work here with per capita regional energy potentials.

In a similar manner, studies in regional self-sufficiency normally address themselves to questions of demand, as well as to questions of supply. In the present study, much space could probably be devoted to a state-by-state analysis of current and future demands for electrical energy (State Energy Data . . . , 1979). For purposes of this particular study, this is probably not necessary. Although it is true that there is presently much variation in state per capita electrical energy use, these variations represent existing conditions, based on facilities presently in place. For example, per capita electricity use is high in the Pacific Northwest because there was an abundant hydropower resource to develop for the use of energy intensive industries such as aluminum smelting, and it was developed. However, this study deals with future supply possibilities, and future increments to existing demands. It seems unlikely that increases in per capita electricity development in the Pacific Northwest will match the fast pace of the past, because the large, relatively inexpensive hydro resource has already been developed and is no longer there as a potential resource. Thus, this paper will make the assumption that future electrical demand will probably reflect rates of regional population growth much more closely in the years to come than has been the case in the past, and will correspondingly assume a reasonable uniformity in future regional per capita increases in electricity demand.

Fifth, all forms of energy, with the exception of thermal fluids, can be transported at least a short distance beyond their state of origin. Interstate sales of electricity, for example, are virtually

ubiquitous. What justification, then, exists for investigating regional or state energy independence based on renewable energy supplies? One reason lies in the power losses and cost increases that are associated with long-distance electricity transfers. However, the major justification, and it is believed a sufficient one, lies in the increasing desire of communities to develop locally generated and controlled forms of energy, particularly electricity. Individuals are erecting electrical wind machines, cities are building small hydro plants on nearby streams, and companies are investing in cogeneration facilities. Many communities and individuals believe that in decentralization and locally owned small facilities lies energy security. OPEC oil embargoes and price increases, not to mention the Three Mile Island accident, have done nothing to dissuade them from this point of view. Thus, even though large centralized generating plants will be with us for the indefinite future, many people are more and more asking themselves, "what potential do we have locally to provide for our own energy needs, so that events outside our control will not leave us with an energy crisis?" One purpose of this paper is to help point the way towards a partial answer to that question.

With the foregoing as an introduction, attention can now be focused on the regional potential of five of the most promising of the alternative sources of electrical energy: hydroelectricity, ocean thermal gradients, geothermal, wind, and direct solar energy. In 1980, hydropower accounted for about 4% of all U.S. electricity production, and geothermal and all other renewables less than three-tenths of one percent (Table 3). Thus, at present, most of these are little used, compared to fossil fuels.

Table 3. U.S. Electricity Production from Renewable Sources (1980)

Energy Source	As a Percentage of U.S. Electricity	As a Percentage of All U.S. Energy Produced
Hydroelectricity	12.1%	4.4%
Geothermal	0.3	0.1
All other renewables	0.01	[a]

[a]The figure for all other renewables, expressed in terms of their electrical production, would be less than one-hundredth of one percent. However, if expressed in terms of total quads (10^{15} Btu) of heat produced from all renewable sources, a significant figure might result, but this number has not been calculated in a comparable form.

Source: Department of Energy, Monthly Energy Review, March 1982.

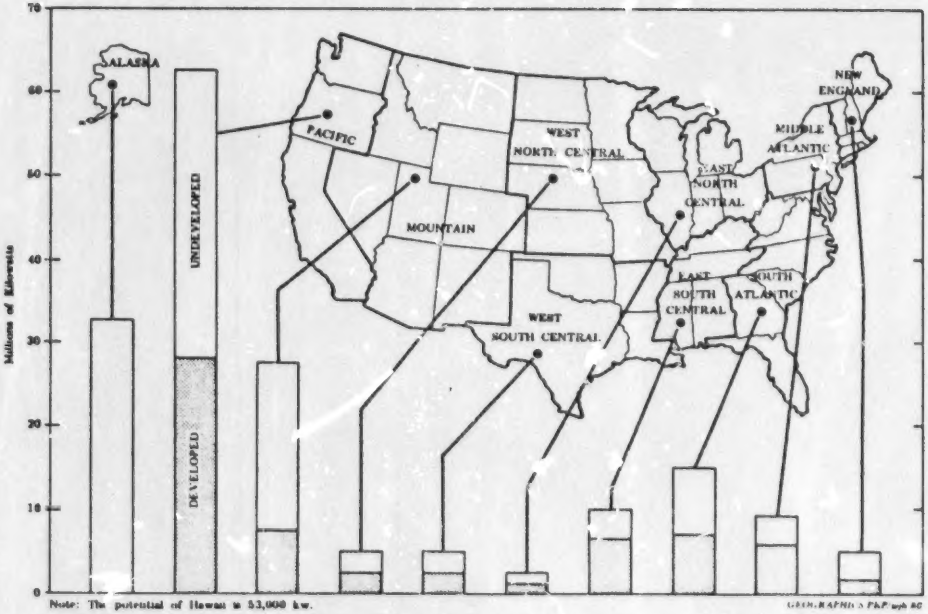
Hydroelectric Energy

Despite the existence of over 1,400 hydroelectric plants in the United States having over 65,000 MW(e) of installed generating capacity, a significant amount of developable hydroelectric power remains. In 1976, the Federal Power Commission (now the Federal Energy Regulatory Commission) estimated that 313,700 megawatts of conventional hydroelectric power remained undeveloped (F.P.C., 1976). For a variety of reasons it is unlikely that this full potential will ever be realized in practice.

At present, only about 35 to 40 percent of the theoretically maximum hydroelectric potential of the United States has been developed. In most regions of the country, the percentage of developed hydropower is between 40 and 60 percent. Only in Alaska, New England, and the Rocky Mountain states is the presently developed portion significantly less than this average amount (Figure 1). In terms of the absolute megawatts of undeveloped potential, about three-quarters of the national total lies west of the Rocky Mountains and in Alaska.

Examining the undeveloped potential at the state level, the top six states are all found in the west, as topography would lead one to expect, but are followed by such eastern states as Pennsylvania, Georgia, West Virginia, Maine, Alabama, New York, Virginia, and South Carolina. Ranked on a per capita basis, according to undeveloped megawatts (MW) per hundred thousand population, Alaska stands far out in front with a figure of 8,314 MW. Idaho ranks first among the conterminous states with 1049 potential MW per 100,000 (Table 4). Montana is

FIGURE 1: REGIONAL UNDEVELOPED HYDROELECTRIC POTENTIAL



Note: The potential of Hawaii is 53,000 kw.

SOURCE: FPC Hydroelectric Power Evaluation (1976), p. 1-8.

Table 4. States with the Largest Remaining Undeveloped Hydroelectric Potential

State	Undeveloped Megawatts (MW)	Population (1980)	Per Capita Undeveloped (MW per 100,000 people)
Alaska	33,283	400,300	8314
Idaho	9,895	943,100	1049
Montana	5,127	783,700	654
Washington	21,289	4,109,600	518
Wyoming	1,273	468,900	271
Oregon	4,874	2,617,400	186
Maine	1,704	1,123,600	152
West Virginia	2,132	1,928,500	111
Utah	1,331	1,454,600	92
Vermont	433	511,300	85
South Dakota	543	687,600	79
New Hampshire	683	919,000	74
North Dakota	407	652,200	62
Colorado	1,635	2,877,700	57
Georgia	2,674	5,396,400	50
California	9,304	23,510,400	40
South Carolina	1,201	3,067,100	39
Alabama	1,514	3,863,700	39
Arkansas	718	2,280,700	31
Kentucky	986	3,642,100	27

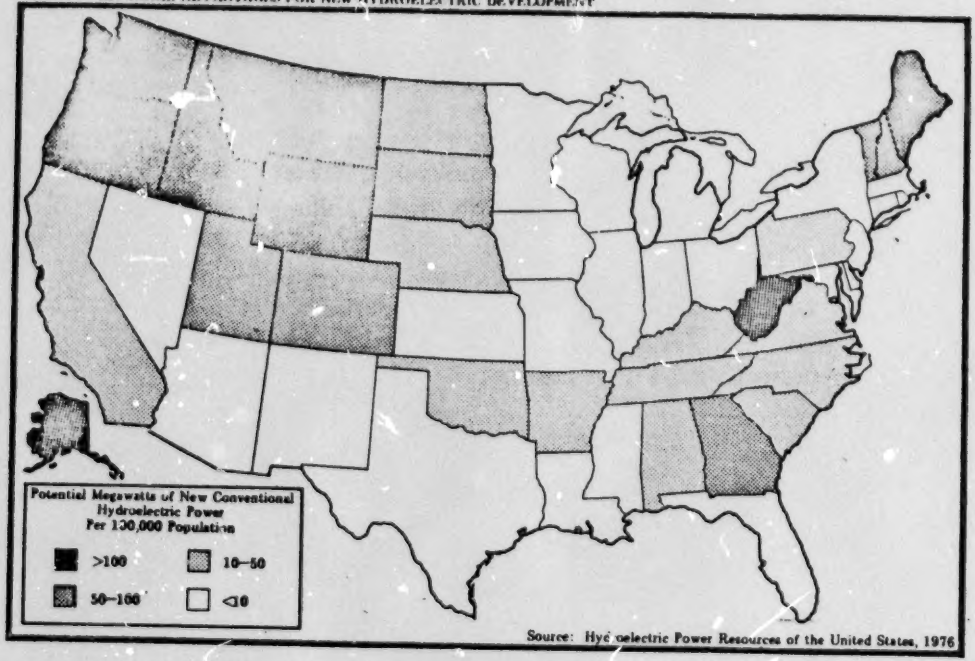
Source: Federal Power Commission, 1976, Table 3; plus 1980 census data.

next with 654 MW, and then Washington (518), Wyoming (271), and Oregon (186). The dominance of the western states can be explained by a combination of smaller populations, topography (i.e., greater elevations), and competing or conflicting uses for rivers and dam sites. Maine leads the eastern states with 152 potential MW per 100,000; West Virginia (111), Vermont (85), and New Hampshire (74) follow. Among the more populous states, California leads with 40; Pennsylvania has 23.

Electrical demand averages 100 to 150 MW per hundred thousand population (excluding heavy industrial users), so many of these state figures appear at first glance to be highly favorable. However, since it is not feasible to develop all of these sites for technical, political, economic, or environmental reasons, the figures in Table 4 should probably be divided by a factor anywhere from two to five to arrive at a feasibly developable figure. On the other hand, Table 4 does not include pumped storage possibilities. Pumped storage represents a fairly ubiquitous form of hydroelectricity, since it utilizes an artificial storage pond into which water is pumped at night for more profitable use at a later time as peak demand-period hydroelectricity.

In summary, the potential advantage enjoyed by certain states in terms of undeveloped hydroelectricity potential is significant. It can be concluded that, even after inserting a feasibility factor, the states of the Pacific Northwest, and several states in the northeast, have an ability to have a significant portion of their electrical energy needs met by hydroelectric sources (Figure 2). The state of Alaska could have virtually all of its electrical needs provided in this manner.

FIGURE 2: REGIONAL ADVANTAGES FOR NEW HYDROELECTRIC DEVELOPMENT



Source: Hydroelectric Power Resources of the United States, 1976

Energy from the Oceans

There are several ways to produce electrical energy from the oceans. These include the use of tides, waves, currents, salinity gradients, and heat gradients. Of these, the only one to be built on a commercial scale to date is a single tidal power plant in France. High costs, coastal protection acts, and technical problems have kept tidal electricity from being more broadly developed. Thus, although tidal power potential is well suited to regional analysis, the probability that few if any new tidal stations will be built in the foreseeable future precludes a need for its detailed analysis in this paper. Similarly, wave and current generating schemes, and salinity gradients, are of too limited potential to warrant detailed discussion given the present embrionic state of the art (Keen, 1982).

The ocean option seen as having the most potential at present is ocean thermal energy conversion (OTEC). This technology utilizes the temperature differentials between tropical surface ocean waters and those at lower depths to vaporize a secondary fluid (such as ammonia or freon) which can be used to operate a turbine-generator unit. The technology exists now to build commercially competitive plants for tropical island electric power grids such as those on Hawaii and Puerto Rico. The first 10 kW field test facility of this type (known as "Mini-OTEC") went on station near Keahole Point, Hawaii in 1979.

The main limiting factor to the regional distribution of OTEC facilities is the spatial proximity of suitable warm-water resource areas to major markets for electricity consumption. The only United States

areas well located to benefit from ocean thermal energy conversion are Hawaii, Florida, and Puerto Rico. Elsewhere, the nearshore temperature differences are too small to produce an economically viable OTEC resource.

Geothermal Electricity

If it were readily accessible, the earth's internal heat could supply the world's energy needs for thousands of years. Economic, technical, and environmental constraints, however, will limit actual geothermal development to only a small fraction of this, and estimates of the magnitude of the recoverable resource vary widely.

A 1975 U.S. Geological Survey (USGS) study suggested that all United States geothermal steam reserves that were economically developable at that time totalled 3,500 megawatt-centuries; that is, these reserves could sustain an electrical output of 3,500 megawatts for 100 years (White and Williams, 1975). Or, at a faster rate of use, they could sustain up to 26,700 MW over a period of 30 years. It envisioned the possibility of 3,000-4,000 megawatts of geothermally generated electricity installed by 1985, and 20,000 MW or more by the year 2000. A later USGS report suggested an output of 23,000 MW for 30 years as the electrical potential of identified (1979) U.S. geothermal resources (Muffler, 1979).

The 1975 USGS report estimated that 72 percent of the nation's potential geothermal electrical generating capacity is in the state of California, and almost all current U.S. production is found within that state. The Department of Energy has made long-range forecasts of

potential geothermal electrical development by state (Table 5). These data indicate a concentration of potential in the states of the Great Basin, Pacific Rim, and Gulf Coast (Figure 3).

Optimistic projections indicate that California's Imperial Valley by itself could sustain a geothermal generating capacity of as much as 50,000 MW for one hundred years, or 100,000 MW for fifty years (F.E.A., 1974). More conservative (and probably realistic) estimates have variously estimated the Valley's potential as 2,000, 4,600, and 8,000 megawatts. In any event, it seems clear that the Imperial Valley's geothermal energy, together with that from Coso Hot Springs in Owens Valley and other promising sites, can one day be providing at least a minor fraction of southern California's electricity needs. Southern California Edison Co., which supplies most of the greater Los Angeles area with electricity, estimated in a 1980 company brochure that by 1996 it can be marketing as much as 650 MW of geothermal electrical energy.

Pacific Gas and Electric, in northern California, currently produces over 900 MW of geothermal electricity at The Geysers. The Geysers is the largest geothermal development in the world at the present time; projects currently under construction will raise installed capacity to about 1500 MW by 1985. Ultimate field capacity could exceed 2000 MW.

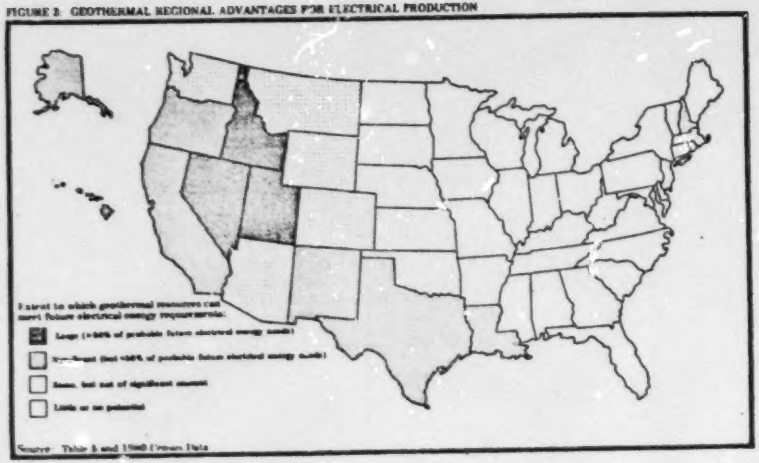
All of the above data refer only to electrical production from geothermal steam (both dry and flashed steam). The electrical potential from "hot dry rock" facilities is unknown at this time, as the

Table 5. Year 2020 Potential Geothermal Electrical Development

State	MW(e) by 1990	MW(e) by 2020
Alaska	?	?
Arizona	200	230
California	5,570	10,270
Colorado	0	0
Hawaii	70	920
Idaho	400	4,950
Louisiana	300	1,200
Montana	50	50
Nevada	050	3,700
New Mexico	350	1,500
Oregon	250	1,150
Texas	725	4,675
Utah	500	3,000
Washington	50	50
Wyoming	0	0
	9,315	31,795

Source: "Geothermal Energy, Research, Development & Demonstration Program," D.O.E., March 1979, pp. 45-60.

FIGURE 3. GEOTHERMAL REGIONAL ADVANTAGES FOR ELECTRICAL PRODUCTION


Extent to which geothermal resources can meet future electrical energy requirements:
Large (>50% of probable future electrical energy needs)
Some, but not of significant amount
Little or no potential

Source: Table 3 and 1980 Census Data

first experimental plant of this type is just now being tested in New Mexico. Even though its long-range potential might be great, hot dry rock potential cannot be treated here, as its regional feasibility has been little studied to date. The same is true for the Gulf Coast's vast geopressured (steam and methane mixture) resources.

Regionally, the western half of the U.S. clearly contains the greatest geothermal development potential. Within the West, the states of California, Oregon, Idaho, Nevada, Utah, and New Mexico seem particularly favored, and pilot projects in many states are now under construction (Table 6). Viewed on a per capita basis, Idaho and Nevada probably could have most of their non-transportation energy needs supplied by geothermal. In addition, if geopressured resources prove to be technically and economically feasible, Texas and Louisiana will have a major new alternative energy resource available to them, as indicated in Table 5.

Wind Energy

Although wind energy, like geothermal, exists in amounts exceeding world energy demands, only a very small fraction is practical for commercial utilization. How much wind energy realistically could be developed in the United States by the year 2000? The California Energy Commission has suggested a potential for that state of 500 MW by 1986, and 7000 MW by the year 2000. These figures appear very optimistic, but the same source believes a total state potential of over 40,000 MW exists (C.E.C., 1980). The President's Domestic Policy Review (DPR) has estimated that about 1.7 quads of energy (500 billion kWh) could be

Table 6. U.S. Geothermal Electricity Projects (other than The Geysers)

State	Site	(MWe) Plant Capacity	Startup or Status
CA	Imperial Valley (East Mesa)	11	1976
CA	Imperial Valley (Brawley)	10 (48)[a]	1980
CA	Imperial Valley, planned (4)	153 total	1982-85
ID	Raft River	5	1980
HI	Puna, Isl. of Hawaii	3 (25)	1981
UT	Roosevelt Hot Springs	1.6 (20)	1981
NV	Beowawe	10	planned

A large number of other projects can be classified as "proposed."

[a]A figure in parentheses indicated planned expansion at the site.

Source: DiPippo, 1980.

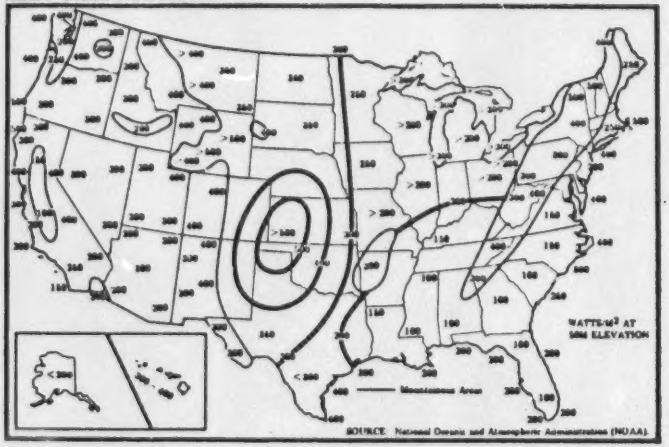
supplied by wind generators throughout the United States by the year 2000. This would represent about two percent of national energy consumption, but about 15 to 20 percent of electrical use. To achieve this, about 125,000 megawatts of installed capacity would be needed, which would imply 50,000 wind machines the size of the large new 2.5 MW units in Goldendale, Washington (Curtis, 1980, pp 1507-8). Although probably technically and economically feasible, it is questionable whether this large a figure is politically, environmentally, and socially feasible. A Congressional goal of 500 MW installed by 1986 also appears ambitious, though perhaps not by 1990. A realistic figure, based on what was on the ground in 1980, expected federal funding levels, and probable private investments, would most likely be between 20 to 50 MW of wind electrical energy in place by 1986, and somewhere in excess of 100 MW by 1990. Over a hundred thousand megawatts by the year 2000 seems highly unlikely, though certainly not impossible.

Regional analyses of wind energy potential are difficult, due mainly to the localized nature of wind patterns and velocity, especially in areas of varied terrain. Most atlases portray a generalized wind pattern map, but this is often of marginal use because of the small scale of the map, and because usually only surface wind speeds are plotted. The "usable wind" is located at least 15 meters (50 feet) above the surface, and thus a more sophisticated wind speed map will be required to provide this manner of information.

The National Oceanic and Atmospheric Administration (NOAA) has attempted to provide such data by measuring average wind speed and translating it into potential wind power (in terms of watts per square meter) at an elevation of 50 meters (164 feet) above the surface. For topographically uniform areas such as the Great Plains, it is possible to construct isolines of wind potential (Figure 4). The area of greatest potential is located (not too surprisingly) in the old dust bowl area, centered around the Oklahoma panhandle. Elsewhere, the maximum potential tends to be found in topographically favored areas, most frequently around hills and mountain passes. In Figure 4, these data can only be shown by spot values representing average wind velocities. The need for more detailed and larger scale studies in mountainous areas is clear for all local jurisdictions.

A map showing comparative advantages by state for wind energy development is probably not practical, since no state has accurately quantified its electrical wind energy potential. However, almost all states have some very favorable areas, based on local landforms, and the generalized pattern is easily discernable from Figure 4. In general, the Great Plains states, ocean-fronting states (but not the Gulf states), and mountainous states all have good potential, with Wyoming, Kansas, New Mexico, Oklahoma, and Montana being especially favored. Only the southeastern, mid-Atlantic, and "corn belt" states have a relatively unfavorable wind characteristics for electricity production. Even in these states, however, specific areas exist where

FIGURE 4 AVERAGE ANNUAL WIND POWER



at least small scale wind energy can probably provide a useful local service.

Solar Energy

Direct solar energy can be used both to generate electricity, and as a source of space and water heating. Both photovoltaics (the direct conversion of sunlight into electricity) and solar thermal devices (those that use steam or other fluids to drive turbine-generators) show promise for considerable electrical generation in the future.

Although solar energy is feasible in virtually all portions of the United States, the goal here is to identify those areas having the greatest promise. Solar feasibility depends on many factors, but generally the attractiveness of solar energy is a function of two local variables, the amount of *in situ* solar insolation and the cost of alternative sources of energy.

The following discussion will examine these two variables in the context of the feasibility of solar hot water heating in areas where electricity must now be used for this purpose. Although this does not represent direct electrical production, it is the equivalent of it, since it frees existing electrical capacity for other uses. Photovoltaic applications which do directly produce electricity have excellent long-term prospects; at the present time, however, they do not lend themselves well to a regional feasibility analysis. Although the insolation factor will be the same for photovoltaics as for water heating systems, the present high (and uniform) cost of solar cell

arrays now precludes a meaningful regional economic analysis for photovoltaics.

Generalized solar insolation levels for the United States can be illustrated by means of isolines (Figure 5). The second variable, the cost of electricity, can be mapped by local marketing areas (Figure 6), based on 1980 local residential rates for a usage of 750 kWh per month (Dept. of Energy, 1980). A usage of 750 kWh/month is used because that is the smallest amount for which data are given in the study that includes electric hot water heaters. The lowest rates exist in the Pacific Northwest and many of the highest are found along the upper Atlantic Coast. These prices are assigned rank values as follows: less than $20 for 750 kWh/month receives a rank value of 1; $20 to $30 is assigned a value of 2; $30 to $40 a value of 3; $40 and above a value of 4.

If the insolation data in Figure 5 are also translated into rank values (by subtracting 1 from the first digit of the Langley quantity), the two sets of rank values can be combined into a single map, thereby generating a rough composite map illustrating the regional feasibilities of solar hot water heating as a substitute for electric water heating. Both sets of rank values have a range of from one to four; thus, the composite map regions will have possible rank values of from two to eight. For purposes of clarity, the composite map has been prepared using four rank values rather than seven, and designates combined rating scores of 2 as "marginal," 3-4 as "fair," 5-6 as "good," and 7-8 as "excellent" (Figure 7).

FIGURE 3: SOLAR INSOLATION MAP FOR THE UNITED STATES

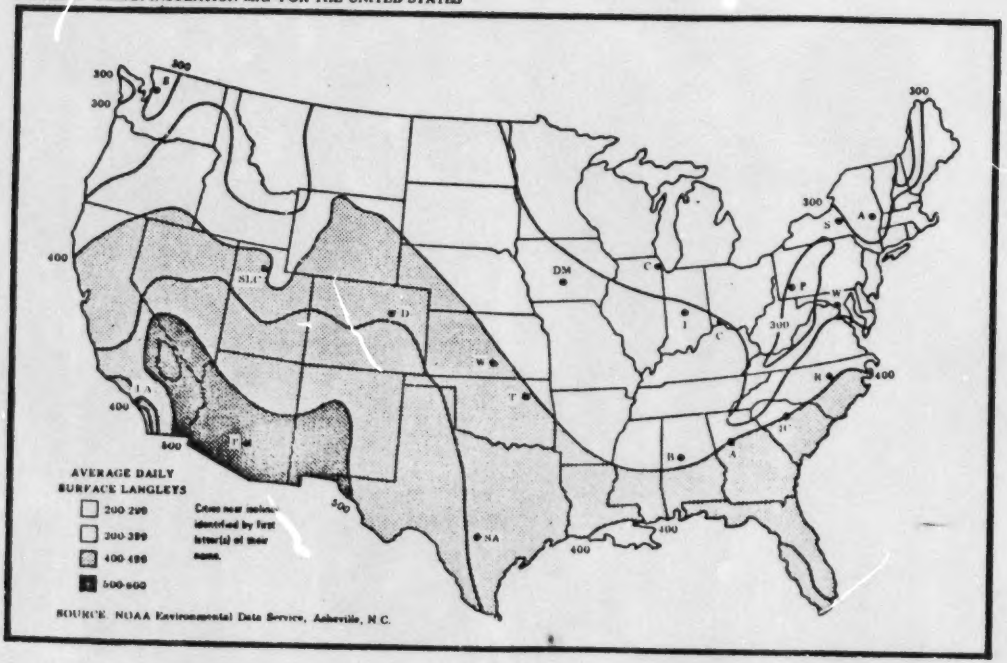
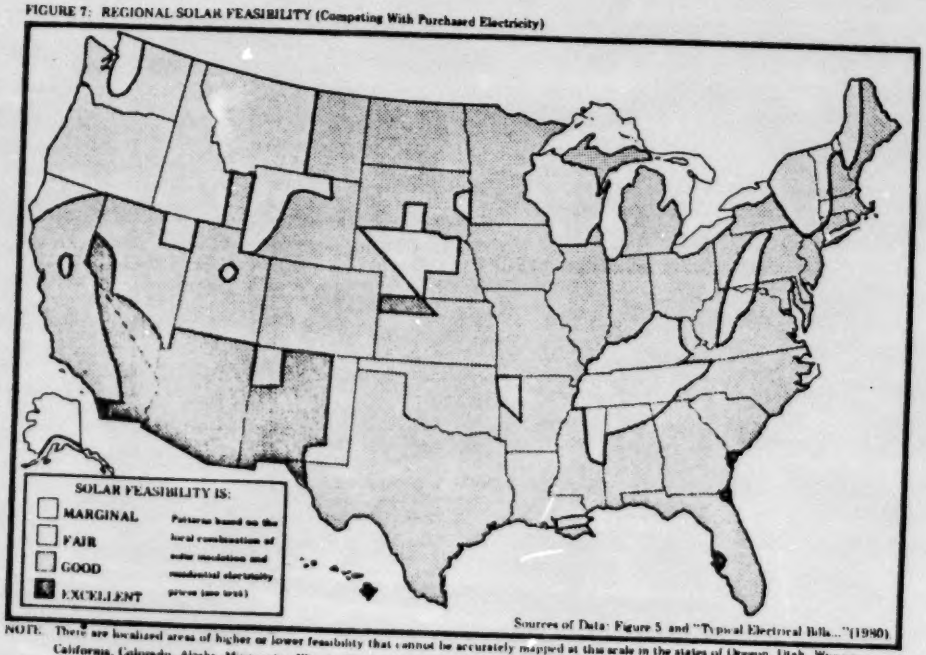


FIGURE 6: MONTHLY RESIDENTIAL ELECTRICAL RATES FOR 750 KWH USAGE

U.S. Average Bill = 36.93 Dollars for 750 KWH/Month
Cost For 750 KWH Per Month
In Dollars
Less Than 20.00
20.00–30.00
30.00–40.00
Above 40.00
Source: D.O.E., Typical Electric Bills, 1980, Table 10

Note: There are localized areas of higher or lower rates that cannot be accurately mapped at this scale in the states of Alaska, California, Colorado Illinois, Massachusetts, Minnesota, New York, Oregon, Pennsylvania, Utah, Wisconsin, and Wyoming. The rate for Washington, D.C. is 27.50 for 750 KWH per month.

FIGURE 7: REGIONAL SOLAR FEASIBILITY (Competing With Purchased Electricity)


SOLAR FEASIBILITY IS:
MARGINAL
FAIR
GOOD
EXCELLENT
Patterns based on the local combination of solar insolation and residential electricity prices (see text)
Sources of Data: Figure 5 and "Typical Electrical Bills..."(1980)

NOTE: There are localized areas of higher or lower feasibility that cannot be accurately mapped at this scale in the states of Oregon, Utah, Wyoming, California, Colorado, Alaska, Minnesota, Illinois, Wisconsin, Pennsylvania, Massachusetts, and New York.

By way of example, in most communities in Minnesota, home electricity rates in January 1980 for 750 kWh per month averaged from $30 to $39, for a price ranking of 3. Solar insolation there ranges from 300-350 langleys, for a solar ranking of 2. These produce a combined feasibility rating of 5 for most of Minnesota. By comparison, on this combined scale, the best regional ratings are found near Phoenix at 8 (4 for both insolation and alternative cost), and the region of lowest feasibility is the Puget Sound (Seattle) area at 2 (1 for insolation; 1 for alternative cost due to inexpensive local hydroelectricity).

Figure 7 is a satisfactory approximation for illustrating the relative cost feasibility of substituting solar devices for existing electrical energy uses throughout the United States. However, additional factors would have to be considered at the local level, such as the seasonal percentage of possible sunshine (it is preferable to have winter as the more cloud-free season), local relief, and personal energy consumption patterns.

Although fossil fuel prices will continue to change, most likely causing the cost of electricity and natural gas to increase over the long run, the incorporation of these cost increases into the rank scales used in Figure 7 should result in only relatively minor alterations in the comparative local evaluations shown on these two maps. This is based on the assumption that fossil fuel prices will rise (and perhaps occasionally fall) more or less proportionally in all regions of the country.

A final point concerning the five alternative energy forms that have been discussed above is that electricity is not the only form of energy that these sources can provide or substitute for. Space heating and mechanical applications are other common end uses. In the case of geothermal energy, considerably more energy can be utilized from low temperature resources (<160°C) than is available from generator-grade steam. Low temperature resources are ideal for space heating and various industrial processes, and can often be applied to uses in the economy where they will directly substitute for scarce fossil fuels. For example, the Department of Energy estimates recoverable low temperature (90°-150°C) resources exist in amounts anywhere from 60 to almost 300 percent greater than the quantity of high temperature resources (I.G.C.C., 1979). Further, the development and use of low-temperature resources generally requires less sophisticated technology and less expense than the development of the hotter resources for electrical generation purposes.

The use of wind energy for mechanical applications long predates its use for generating electricity, of course, and mechanical applications will probably always be an important use in remote areas. In terms of total BTU equivalents, however, electrical generation seems destined to be the dominant use of wind energy in the future. Hydropower is currently of very minor importance for mechanical applications, and this is apt to remain the case. OTEC is being designed exclusively for electrical generation purposes, though aquaculture is a potential associated activity.

Direct solar energy is today used primarily for non-electrical applications, predominantly hot water heating, but this may not always be the case. Regardless of the future success of photovoltaic and solar thermal electrical systems, however, both active and passive solar heating applications seem certain to also have a tremendous expansion potential in the future.

A Map of Regional Alternative Energy Potential

The preceding sections have formulated some conclusions concerning the areas of the United States in which five promising alternative energy options might have the greatest potential. It would be useful to try to draw this information together, and to see what regional and national conclusions might be inferred from the combined data. Generalities only will be possible, since we are dealing with several different kinds of potential energy resources, as well as with a variety of uncertainties concerning the future feasibility of each.

As noted earlier, this study has not considered forms of energy that can be so easily transported over long distances that they are functionally ubiquitous, nor certain nonconventional forms that tend to be fairly widespread in occurrence, such as urban wastes and, to an extent, biomass. Rather, it has investigated alternative electrical energy forms such as geothermal, OTEC, hydroelectricity, wind, and solar which are spatially variable, and hence lend themselves better to regional analyses. The areal extent of these regional concentrations have been examined and empirically collated to discover where

overlapping areas of advantage of two or more of these energy forms suggest the presence of a larger alternative energy region. In this manner, a generalized national map of regional advantages for alternative electrical energy resources emerged (Figure 8). These regional advantages are also summarized in Table 7.

The fourteen energy regions described in Figure 8 include a separate consideration of the locations of major new fossil fuel deposits as well, so as to present a more comprehensive picture of possible regional energy development patterns up to the year 2000. Each of the regions is identified as ranking high, moderate or low in terms of both future alternative (AE) and fossil fuel (FF) energy production. Future nuclear fission development has not been included in Figure 8, both because nuclear power stations may be constructed almost anywhere and because the extent of its future development is so uncertain at the present time.

A significant conclusion which emerges from this study is that several of the less populated states could probably be obtaining almost all of their electrical needs from alternative sources by the mid-to-late 1990's. These would include Alaska, Hawaii, Idaho, Maine, Montana, Nevada, New Mexico, Oregon and Wyoming. One of these states, Hawaii, has announced its intention to do precisely that (Shupe, 1982). In addition, Arizona, Louisiana, Oklahoma, Utah, Vermont, Washington, and West Virginia could have a major share of their electrical needs so met. California and Texas also have very large alternative energy resources available for development, but their large populations will require them to continue to depend on fossil fuel or nuclear sources to a large extent as well.

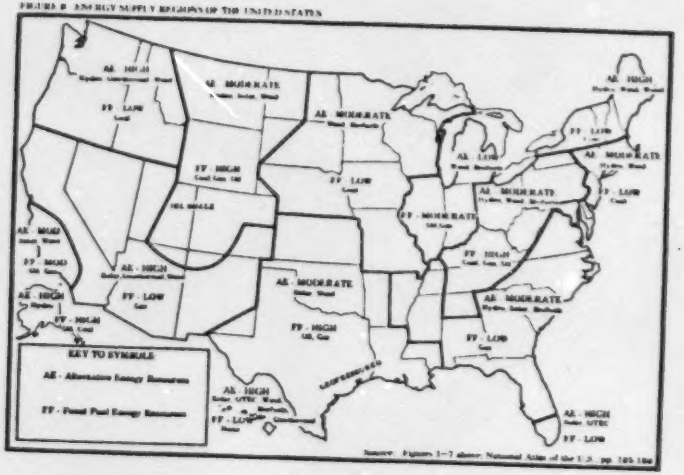

AE - HIGH
AE - MODERATE
AE - LOW
FF - HIGH
FF - MODERATE
FF - LOW
KEY TO SYMBOLS:
AE - Alternative Energy Resources
FF - Fossil Fuel Energy Resources

Table 7. Alternative Energy Supply Regions of the United States

Region (see Figure 8)	Alternative Energy Resources	Fossil Fuels
1. Northern Northeast	High	Low
2. Coastal Northeast	Moderate	Low
3. Southeast	Moderate	Low
4. South Florida (plus Puerto Rico)	High	Low
5. Appalachian states	Moderate	High
6. Eastern Midwest	Low	Moderate
7. Western Midwest	Moderate	Low
8. South Central	Moderate*	High
9. Rocky Mountains	Moderate	High
10. Pacific Northwest	High	Low
11. Southwest	High	Low
12. Coastal California	Moderate	Moderate
13. Hawaii	High	Low
14. Alaska	High	High

*High if geopressured resources prove widely developable.

Source: See text.

It is clear that Figure 8 is a generalization, and attempts only to summarize cartographically the conclusions drawn forth in the previous sections of this study. It may be taken as a first approximation of a national map of nonconventional energy potential, subject to future refinement. It will have served a useful purpose if it stimulates a broader regional consciousness as to the nature of attractive energy options locally available.

It must also be kept in mind that Figure 8 shows only potential for the development of alternative energy resources. The decision as to whether or not they will actually be developed is a political and economic one that local jurisdictions and industries will ultimately have to assess for themselves. The specific nature of the decision will reflect local biases, and may involve subsidies, environmental trade-offs, or perhaps simply regulatory agency approval. In some cases, such as geothermal or large hydroelectric facilities, the environmental trade-offs may be significant, but that is a topic for a separate study. The price and availability of conventional fossil fuels will also be an important factor, but so will each local region's sentiments regarding the future of its own energy supply and its natural environment. In some cases these will not be easy political decisions, but the energy questions of the 1980's and 1990's will more and more frequently revolve around them.

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